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TECHNICAL NOTE

D-1263

EFFECTS OF FOREBODY LENGTH ON THE STABILITY AND CONTROL CHARACTERISTICS AT A MACH NUMBER OF 2.01 OF A CANARD AIRPLANE CONFIGURATION WITH A TRAPEZOIDAL ASPECT-RATIO-3 WING

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EFFECTS OF FOREBODY LENGTH ON THE STABILITY AND CONTROL CHARACTERISTICS AT A MACH NUMBER OF 2.01 OF A CANARD AIRPLANE CONFIGURATION WITH A TRAPEZOIDAL ASPECT-RATIO-3 WING[1]

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By M. Leroy Spearman and Cornelius Driver

SUMMARY

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the stability and control characteristics of a canard airplane configuration equipped with a trapezoidal aspect-ratio-3 wing. Three bodies having length-diameter ratios of 9.45, 11.1, and 12.5 were investigated. The ratio of canard exposed area to wing total area was 0.0707. The model was equipped with a single, swept, body-mounted vertical tail.

The experimentally determined variations of control effectiveness C_{m_δ} and longitudinal stability parameter $\partial C_m/\partial C_L$ with canard volume were in reasonably close agreement with estimated variations. As the body length was increased, the maximum trimmed values of lift-drag ratio L/D decreased at low stability levels and increased at high stability levels.

At low angles of attack, the directional stability C_{n_β} decreased with increasing body length primarily because of the increase in instability of the body. With increasing angle of attack, an additional decrease in C_{n_β} occurred because of a decrease in tail contribution. This decrease in tail contribution became progressively worse as the body length increased.

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[1]Supersedes recently declassified NASA Memorandum 10-14-58L by M. Leroy Spearman and Cornelius Driver, 1958.

INTRODUCTION

A research program is underway at the Langley 4- by 4-foot supersonic pressure tunnel to determine the aerodynamic characteristics of several canard airplane configurations. Various phases of the program are presented in references 1 to 5. As an extension to this program, an investigation has been made at a Mach number of 2.01 to determine some effects of forebody length on the aerodynamic characteristics of a canard configuration.

Increasing the forebody length could serve a twofold purpose in providing increased body volume and in providing a longer moment arm for the canard surface. However, a limiting factor to consider might be the tendency toward increased longitudinal and directional instability of the body as the forebody length is increased. In addition, some changes in the interference effects of the forebody and canard flow fields on the wing and vertical tail might be expected as the forebody length is varied. The purpose of the present investigation was to determine the extent to which the longitudinal and lateral stability and control characteristics of a generalized canard configuration might be affected by changes in the forebody length. The configuration investigated had a midwing and canard of trapezoidal plan form and a body-mounted swept vertical tail. Three different forebody lengths were investigated.

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SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching-moment coefficients referred to the stability-axis system and rolling-moment, yawing-moment, and side-force coefficients referred to the body-axis system. The reference center of moments for the basic data was on the body center line at a point 12 inches forward of the base for all bodies.

C_L lift coefficient, $\frac{\text{Lift}}{qS_W}$

C_D drag coefficient, $\frac{\text{Drag}}{qS_W}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_W\bar{c}_W}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS_Wb}$

C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS_w b}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS_w}$
q	free-stream dynamic pressure, lb/sq in.
S_w	wing area including body intercept, sq in.
S_c	exposed area of canard surface, sq in.
b	wing span, in.
$\bar{c}_w$	wing mean geometric chord, in.
l	distance from canard surface hinge line to reference center of moments, in.
M	Mach number
α	angle of attack, deg
β	angle of sideslip, deg
δ_c	angle of canard deflection, deg
L/D	lift-drag ratio, C_L/C_D
C_{n_β}	directional-stability parameter, $\partial C_n/\partial\beta$
ΔC_{n_β}	incremental value of C_{n_β} due to the vertical tail
C_{l_β}	effective-dihedral parameter, $\partial C_l/\partial\beta$
C_{Y_β}	side-force parameter, $\partial C_Y/\partial\beta$
$\partial C_m/\partial C_L$	longitudinal stability parameter (measure of static margin at δ_c and $C_L = 0$)
C_{m_δ}	canard pitching effectiveness, $\partial C_m/\partial\delta_c$

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$\frac{S_c l}{S_w \bar{c}_w}$ canard volume coefficient

Components and Subscripts:

V vertical tail

max maximum value

trim value at $C_m = 0$

w wing

c canard

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MODELS AND APPARATUS

Details of the model are shown in figure 1 and the geometric characteristics are presented in table I. Coordinates of the body are given in table II. The various body lengths were obtained by using the same forebody and afterbody with the addition of cylindrical center-body adapters of different lengths. The canard-surface hinge-line location was fixed with respect to the forebody and hence the canard surface moved forward with the forebody as the overall body length was increased. The canard surface was motor driven and the deflections were set by remote control.

Force and moment measurements were made through the use of a six-component internal strain-gage balance. The model was mounted in the tunnel on a remotely controlled rotary sting.

TESTS, CORRECTIONS, AND ACCURACY

The tests were made in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01, a stagnation pressure of 10 pounds per square inch absolute, and a stagnation temperature of 100° F. The stagnation dewpoint was maintained sufficiently low (-25° F or less) so that no significant condensation effects were encountered in the test section. The angles of attack and sideslip were corrected for deflection of the balance and sting under load. The base pressure was measured and the drag force was adjusted to a base pressure equal to the free-stream static pressure.

The estimated variations in the individual measured quantities based on zero shifts and repeatability are as follows:

C_L	±0.0003
C_D	±0.0010
C_m	±0.0004
C_l	±0.0004
C_n	±0.0001
C_Y	±0.0015
α, deg	±0.2
β, deg	±0.2
δ_c, deg	±0.1
M	±0.01

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DISCUSSION

Longitudinal Stability

The effects of forebody length on the aerodynamic characteristics in pitch with $\delta_c = 0^{\circ}$ and for a constant center-of-gravity position are shown in figure 2. Under these conditions the primary effect of increasing the forebody length is to reduce the static stability. In addition, a slight tendency toward reduced stability at high lifts becomes apparent as the body length is increased. The maximum value of L/D is reduced slightly as the body length is increased because of a small increase in drag.

The effects of the addition and deflection of the canard surface for the various body lengths are shown in figure 3. As would be expected, the addition of the canard surface provides a decrease in static stability that becomes less as the body length decreases. For all body lengths, increasing the canard deflection results in a tendency toward increased stability because of a decrease in canard pitching effectiveness with increasing lift.

For each body length, the addition and deflection of the canard surface cause the maximum values of L/D to decrease progressively primarily because of an increase in drag.

The experimental and estimated variations with canard volume coefficient of the canard pitching effectiveness C_{m_δ} at $\alpha = 0^{\circ}$ and the static longitudinal stability $\partial C_m/\partial C_L$ at $\delta_c = 0^{\circ}$ are shown in figure 4. The estimated variations were obtained by the method of reference 6 but do not include interference effects between the canard surfaces and the wing. Although the results indicate some difference in the experimental and estimated values of C_{m_δ} and $\partial C_m/\partial C_L$, the variations of C_{m_δ} and $\partial C_m/\partial C_L$ with canard volume coefficient are predicted reasonably well.

The effects of body length on the longitudinal trim characteristics are shown in figure 5. For a constant center-of-gravity position (fig. 5), as the body length increases, the trim lift effectiveness increases and the maximum value of L/D increases. This increase in trim lift effectiveness results both from the increase in C_{m_δ} and the decrease in stability level $\partial C_m/\partial C_L$ that occurs because of the increase in canard surface moment arm l. Thus, with increasing body length, the canard surface is able to produce higher trimming moments but because of the decrease in stability is required to produce less. Hence, lower control deflections are required for trimming and the result is an increase in maximum L/D with increasing forebody length when the center-of-gravity position is held constant.

However, the control deflections required for trimming, and thus the trimmed L/D, depend on the stability level. In order to compare the effects of body length for constant stability levels, the results presented in figure 3 have been used to determine the variation of maximum trimmed L/D with $\partial C_m/\partial C_L$ for each body. (See fig. 6.) As might be expected, the maximum values of trimmed L/D decrease with increasing stability level for each body. However, as the body length is increased, the values of maximum trimmed L/D decrease at low stability levels and increase at high stability levels. For a static margin of about $0.17\bar{c}_w$, the maximum trimmed L/D is about the same with each body. At lower stability levels, where little control deflection is required for trimming, the decrease in L/D with increasing body length results primarily from a slight increase in drag. At higher stability levels, where considerable control deflection is required for trimming, the increase in maximum trimmed L/D with increasing body length results from the higher trim lift effectiveness of the canard surface that permits trimming with less control deflection for the longer bodies than for the shorter bodies. The increase in canard effectiveness with increasing body length is a result of the increase in the canard surface moment arm. The increase in canard moment arm exists even for the condition of constant stability since, because of the moment contribution of the wing, the center-of-gravity shift required to provide constant stability is small compared with the differences in forebody length.

Since the highest trimmed L/D was obtained with the shortest body at low stability levels, it may be of interest to inspect the moment

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characteristics for such conditions. The effects of control deflection on the pitching-moment characteristics of the short body configuration with a static margin of $0.03\bar{c}_w$ are shown in figure 7. The moment variations with lift are reasonably linear and indicate no regions of instability over a wide range of lift coefficients. Because of a slight positive value of C_m at zero lift, the configuration trims with $\delta_c = 0^\circ$ at a lift coefficient of about 0.19. This trim condition, as indicated in figures 3(c) and 6, corresponds to the maximum L/D of about 6.6.

Lateral and Directional Stability

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The effects of body length on the aerodynamic characteristics in sideslip are shown in figure 8 for three angles of attack. As might be expected, the directional stability decreases with increasing body length since all the increase in length is forward of the center of gravity. At $\alpha \approx 0^\circ$, the variation of C_n with β becomes increasingly nonlinear and unstable with increasing body length at high angles of sideslip and at the higher angles of attack the longer bodies become unstable throughout the sideslip range.

The variation of sideslip derivatives with angle of attack are summarized in figure 9 for each body with the vertical tail on and off and with the canard surface on and off. At low angles of attack, the decrease in C_{n_β} with increasing body length is primarily an effect of the change in body moment, since the decrease is essentially unaffected by the vertical tail or canard surface. The variation of C_{n_β} with angle of attack with the vertical tail off remains essentially constant whereas, with the vertical tail on, C_{n_β} decreases with increasing α because of a decrease in the tail contribution. This decrease in tail contribution to C_{n_β} with increasing angle of attack becomes progressively worse as the body length is increased. (See fig. 10.) This effect is associated with an upward displacement in the region of the vertical tail of the forebody-induced vortex as the forebody length is increased. A comparison of figures 9(a) and 9(b) indicates that the presence of the canard surface has only a slight effect on the variation of C_{n_β} with α. Some improvement in the level of C_{n_β} and in the variation of C_{n_β} with α might be expected through the use of ventral fins or twin vertical tails. (See ref. 5.) In fact, twin vertical tails located on the wing outboard of the forebody vortex may experience an increase in effectiveness with increasing angle of attack.

In general, increasing the forebody length results in a small increase in the positive dihedral effect $\left(-C_{l_\beta}\right)$. The effects of forebody length on C_{Y_β} are consistent with the effects shown for C_{n_β}. It should be remembered that the longitudinal stability decreases as the forebody length is increased; therefore, for a constant static margin, the center-of-gravity location would move forward and the vertical tail moment arm would increase as the forebody length increases. The effect of body length on the directional stability for a constant static margin of $0.17\bar{c}_w$ is shown in figure 11. Although the directional stability characteristics for a constant static margin (fig. 11) are generally similar to those for a constant center-of-gravity position (fig. 9(a)), the effects of body length are slightly less for the case of constant static margin.

CONCLUSIONS

An investigation has been made in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the effects of body length on the stability and control characteristics of a canard airplane configuration equipped with a trapezoidal wing. The configurations investigated included three bodies having length-diameter ratios of 9.45, 11.1, and 12.5. The results of the investigation indicated the following:

1. The variations of control effectiveness C_{m_δ} and longitudinal stability parameter $\partial C_m/\partial C_L$ with canard volume could be predicted reasonably well by the use of existing estimating procedures.

2. At low stability levels, where little control deflection is required for trimming, the maximum trim values of lift-drag ratio decreased with increasing body length because of a slight increase in drag.

3. At high stability levels, where considerable control deflection is required for trimming, the maximum trim values of lift-drag ratio increased with increasing body length because of the increase in trim lift effectiveness of the canard surface that permits trimming with less control deflection as the body length increases.

4. At low angles of attack, the directional stability C_{n_β} decreased with increasing body length primarily because of the increase in instability of the body.

5. With increasing angle of attack, an additional decrease in C_{n_β} occurred because of a decrease in tail contribution. This decrease in

tail contribution became progressively worse as the body length increased because of an upward displacement in the region of the vertical tail of the forebody-induced vortex.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., July 22, 1958.

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2. Spearman, M. Leroy, and Driver, Cornelius: Effects of Canard Surface Size on Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L57L17a, 1958.

3. Spearman, M. Leroy, and Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics at Mach Number 2.01 of a 60° Delta-Wing Airplane Configuration Equipped With a Canard Control and With Wing Trailing-Edge Flap Controls. NACA RM L58A20, 1958.

4. Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics of Various Combinations of the Component Parts of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NASA MEMO 10-1-58L, 1958.

5. Spearman, M. Leroy, and Driver, Cornelius: Some Factors Affecting the Stability and Performance Characteristics of Canard Aircraft Configurations. NACA RM L58D16, 1958.

6. Pitts, William C., Nielsen, Jack N., and Kaattari, George E.: Lift and Center of Pressure of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds. NACA Rep. 1307, 1957.

TABLE I.- GEOMETRIC CHARACTERISTICS OF MODEL

	Long	Mid	Short
Body:			
Maximum diameter, in.	3.33	3.33	3.33
Length, in.	41.5	37.0	31.5
Base area, sq in.	8.71	8.71	8.71
Fineness ratio	12.5	11.1	9.45

Wing:	
Span, in.	24
Root chord at body center line, in.	12.8
Tip chord, in.	3.2
Area, sq in.	192
Aspect ratio	3
Taper ratio	0.25
Mean geometric chord, in.	8.96
Sweep angle of leading edge	30° 58'
Sweep angle of 75-percent-chord line, deg	0
Thickness ratio, percent chord	4
Section	Circular arc
Canard:	
Total exposed area, sq in.	13.59
Ratio of exposed area to wing area	0.0707
Section	Hexagonal
Constant thickness, in.	0.1875
Leading-edge angle normal to leading edge, deg	10
Trailing-edge angle normal to trailing edge, deg	10
Vertical tail:	
Total exposed area, sq. in.	23.42
Leading-edge sweep, deg	60
Panel aspect ratio	1.11
Taper ratio	0.314
Section	Wedge slab
Leading-edge angle normal to leading edge, deg	10.6
Slab constant thickness, in.	0.1875

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TABLE II.- BODY COORDINATES

Body station, in.	Radius, in.
Forebody (all bodies)	
0	0
.297	.076
.627	.156
.956	.233
1.285	.307
1.615	.378
1.945	.445
2.275	.509
2.605	.573
2.936	.627
3.267	.682
3.598	.732
3.929	.780
4.260	.824
4.592	.865
4.923	.903
5.255	.940
5.587	.968
5.920	.996
6.252	1.020
6.583	1.042
Short body	
17.75	1.667
31.50	1.667
Mid body	
17.75	1.667
37.00	1.667
Long body	
17.75	1.667
41.50	1.667

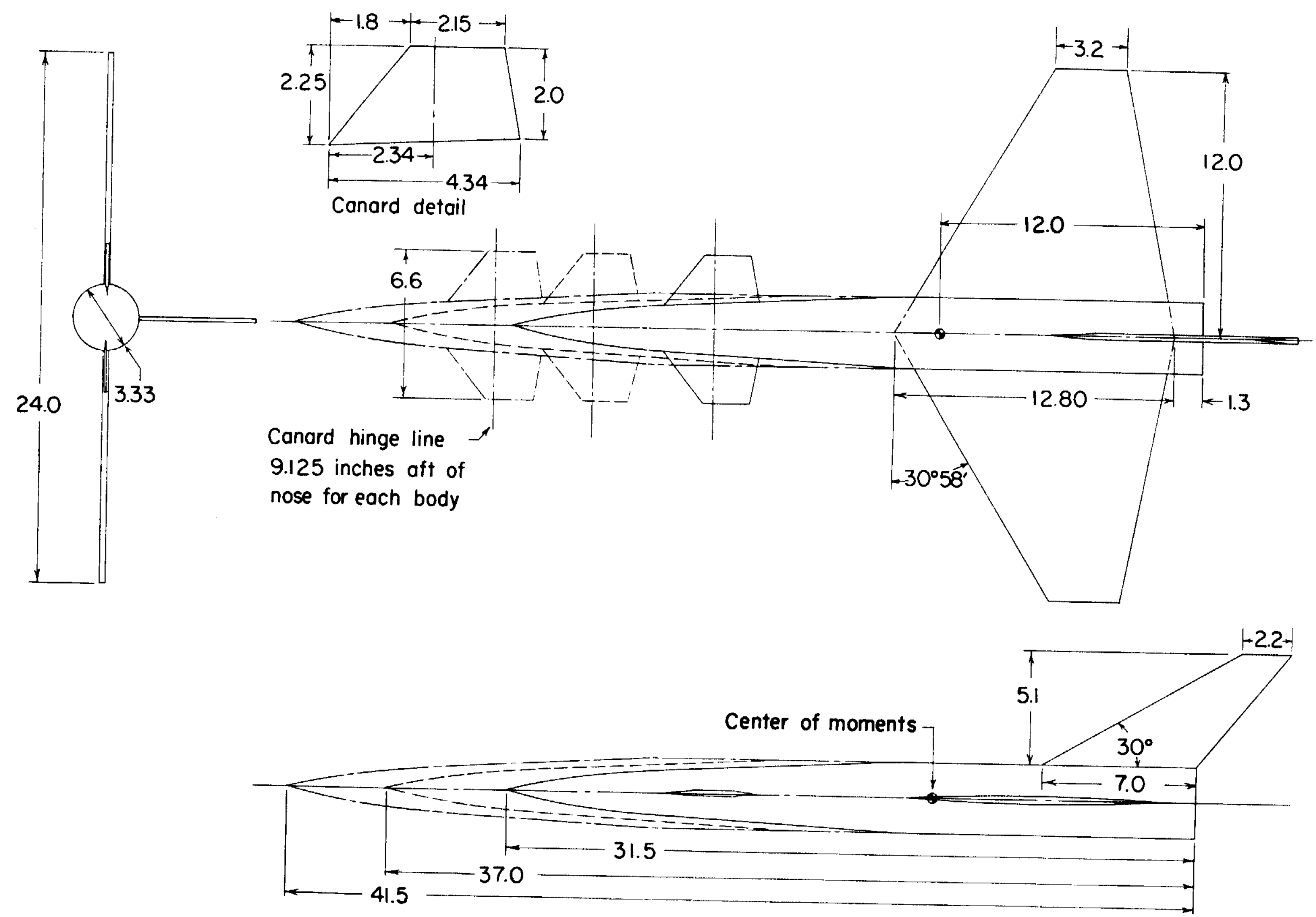

Figure 1.- Details of model. All dimensions are in inches except where noted.

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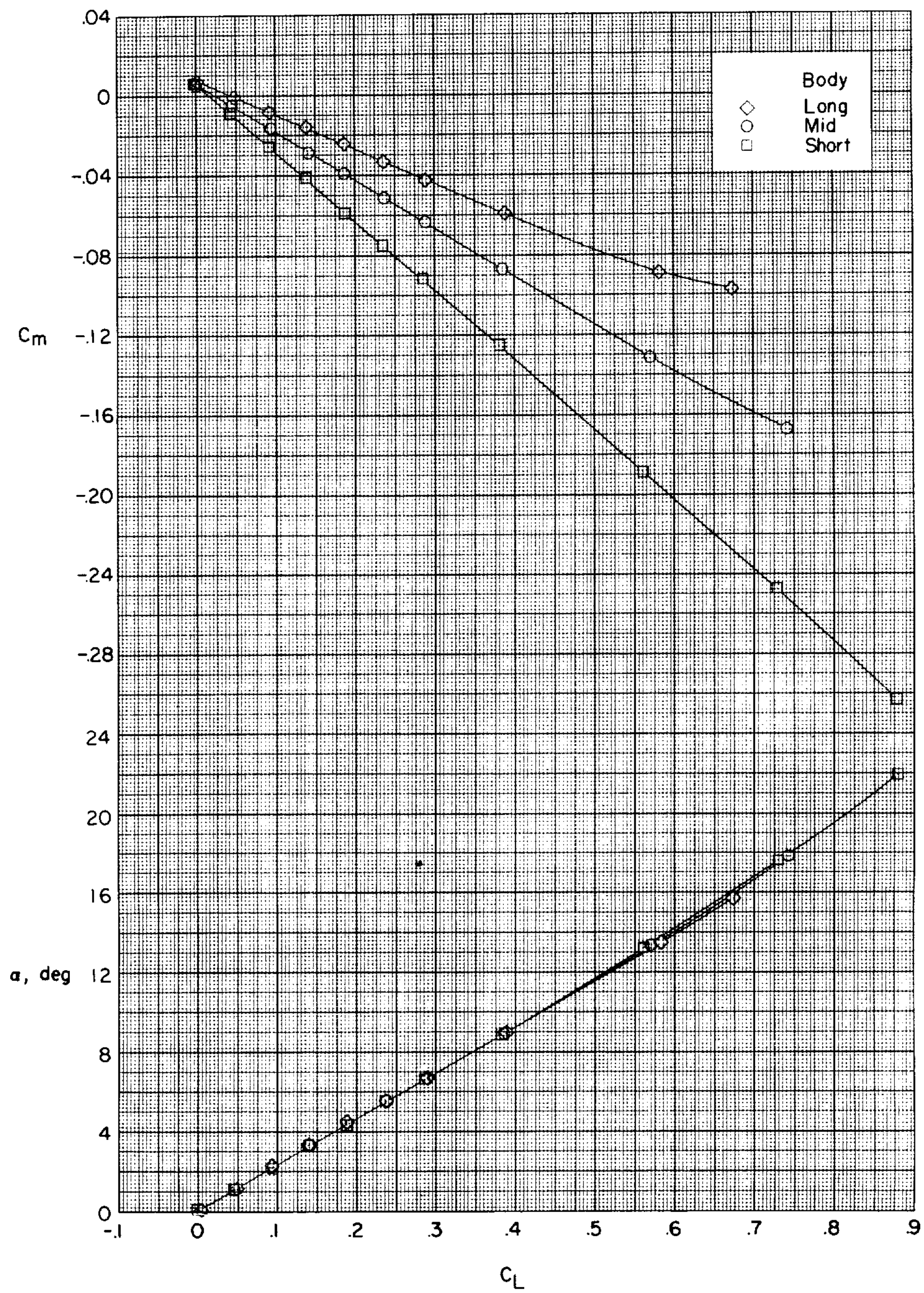
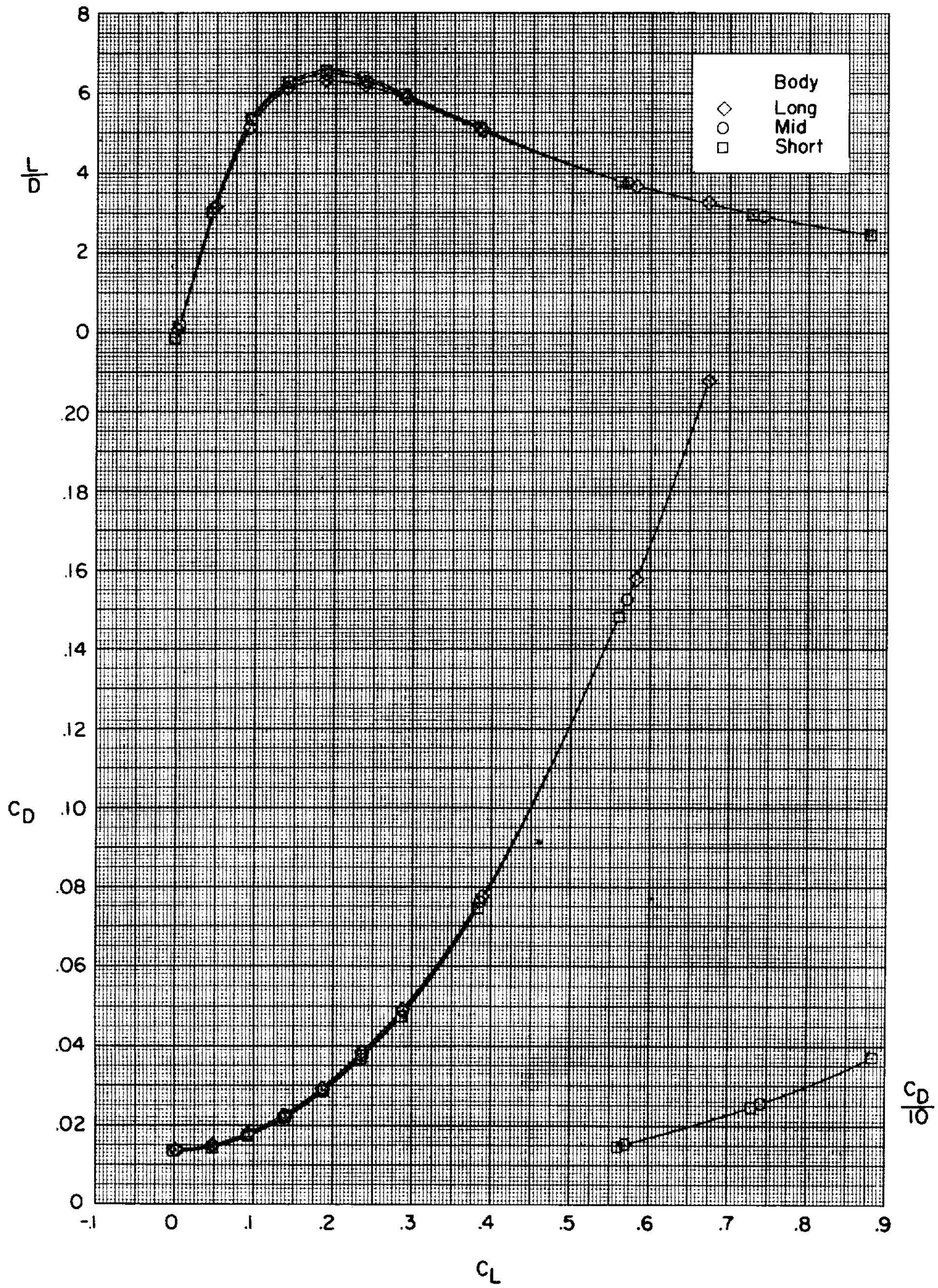


(a) Variation of C_m and α with C_L.

Figure 2.- Effect of forebody length on aerodynamic characteristics in pitch. $\delta_c = 0^{\circ}$.



(b) Variation of L/D and C_D with C_L.

Figure 2.- Concluded.

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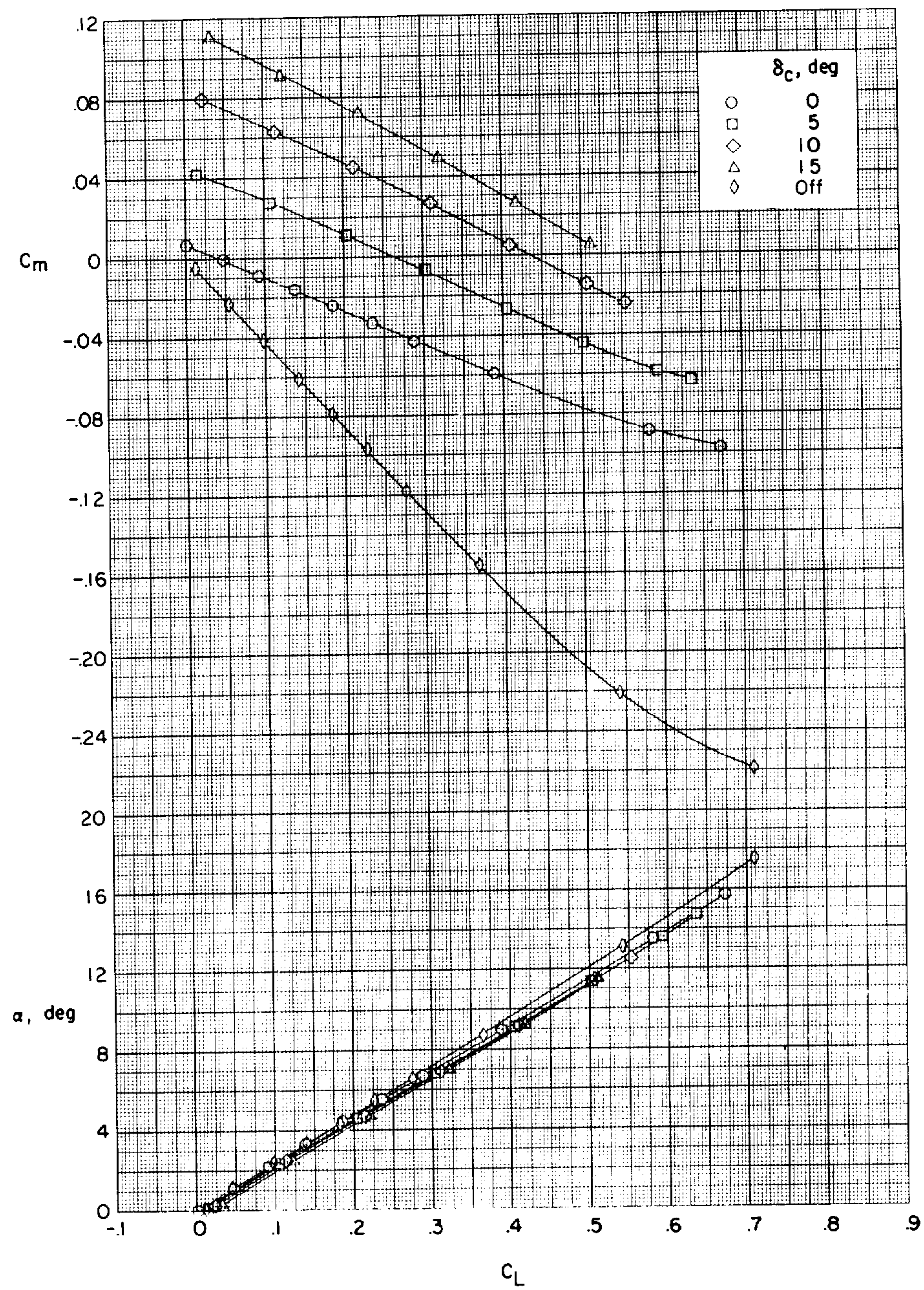
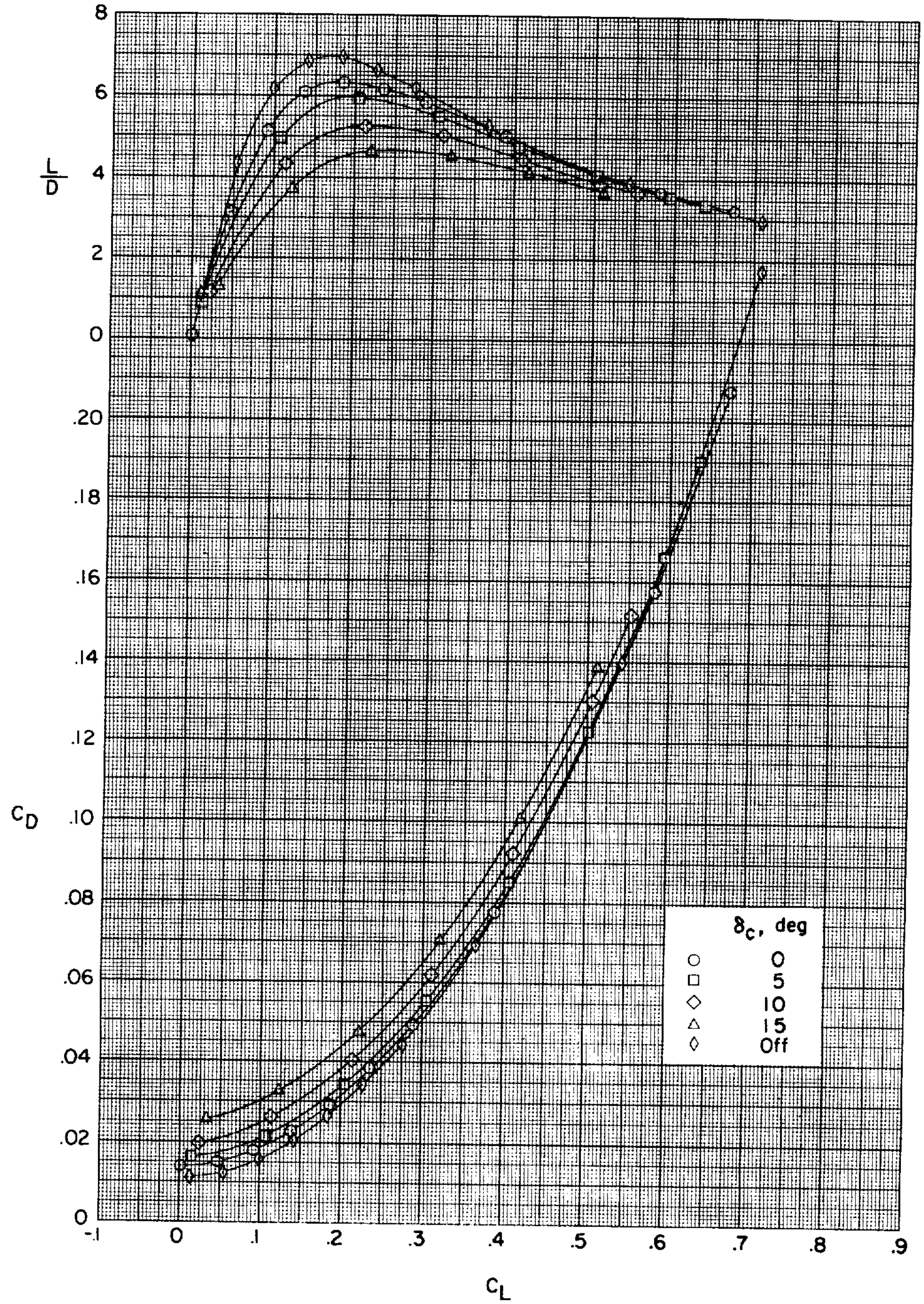


(a) Long body.

Figure 3.- Effect of canard deflection on aerodynamic characteristics in pitch for various body lengths.



(a) Concluded.

Figure 3.- Continued.

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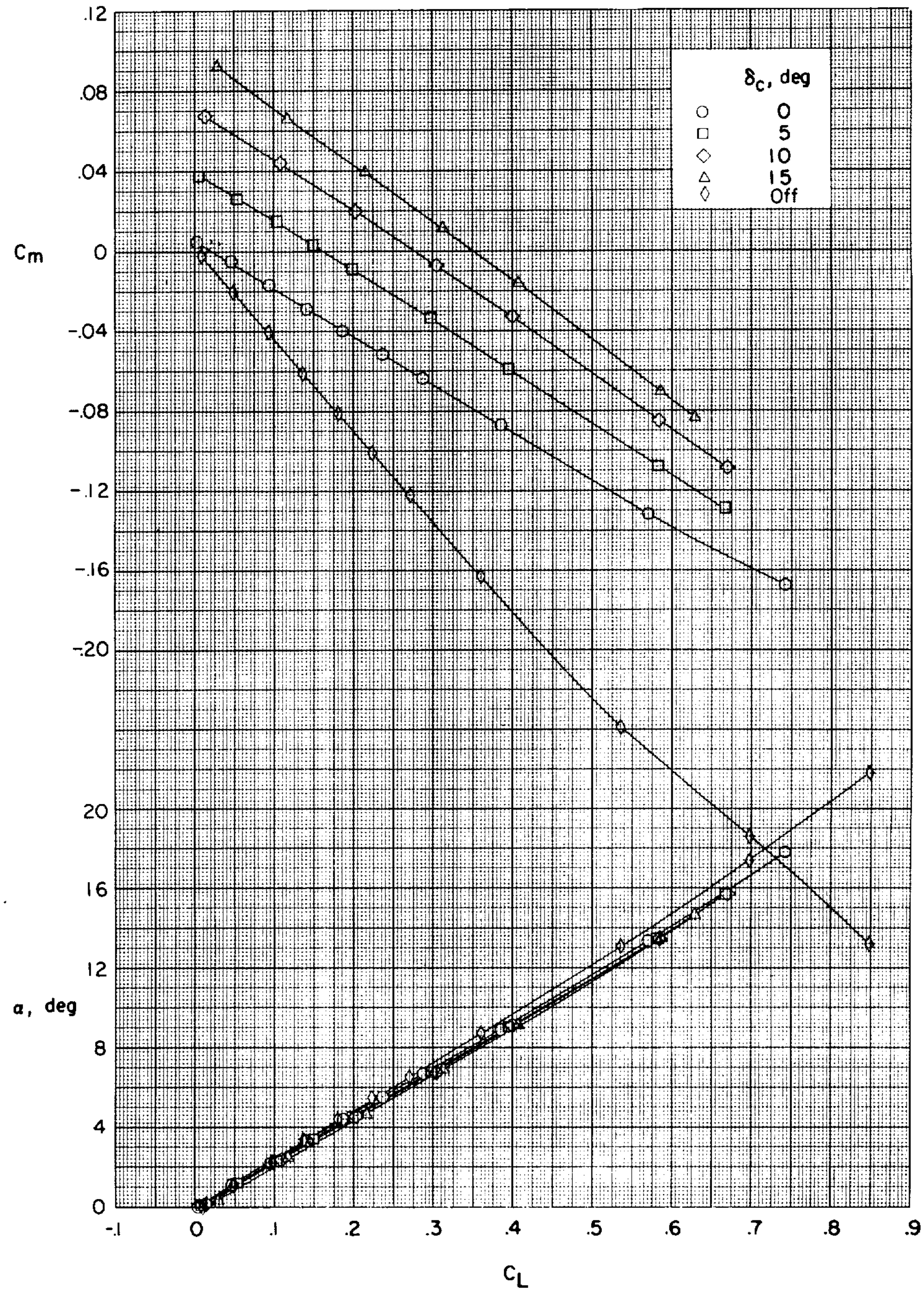
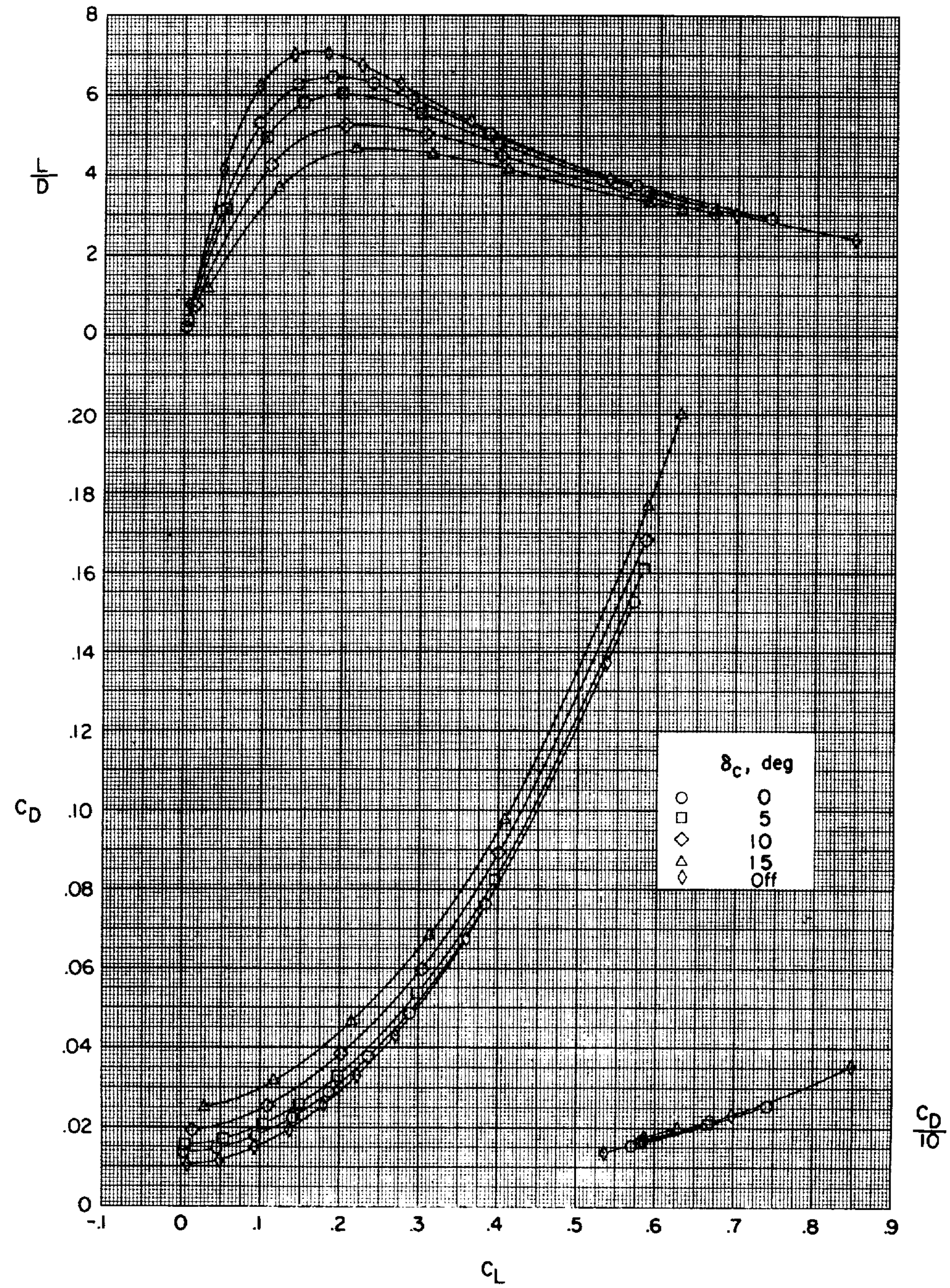


(b) Mid body.

Figure 3.- Continued.



(b) Concluded.

Figure 3.- Continued.

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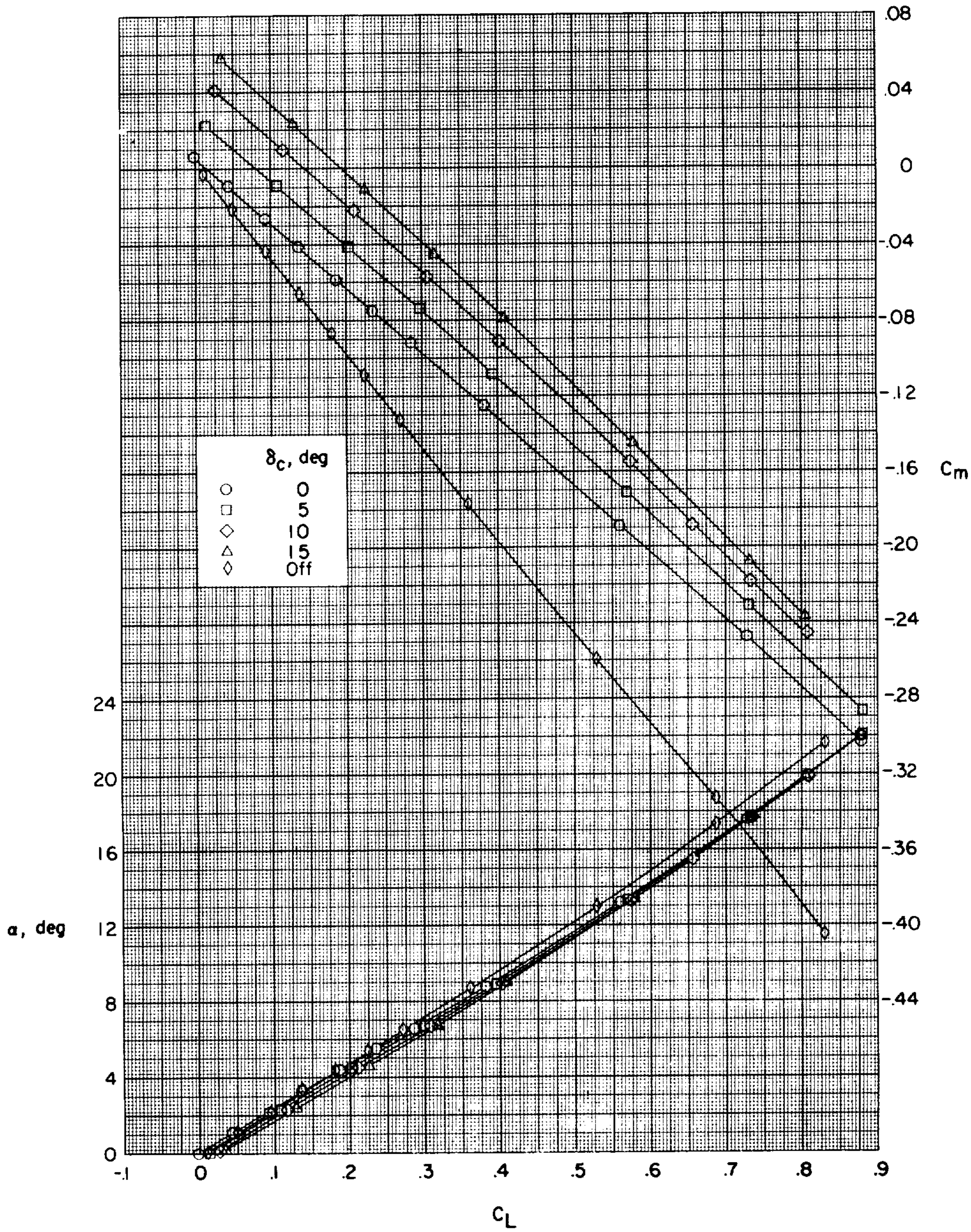
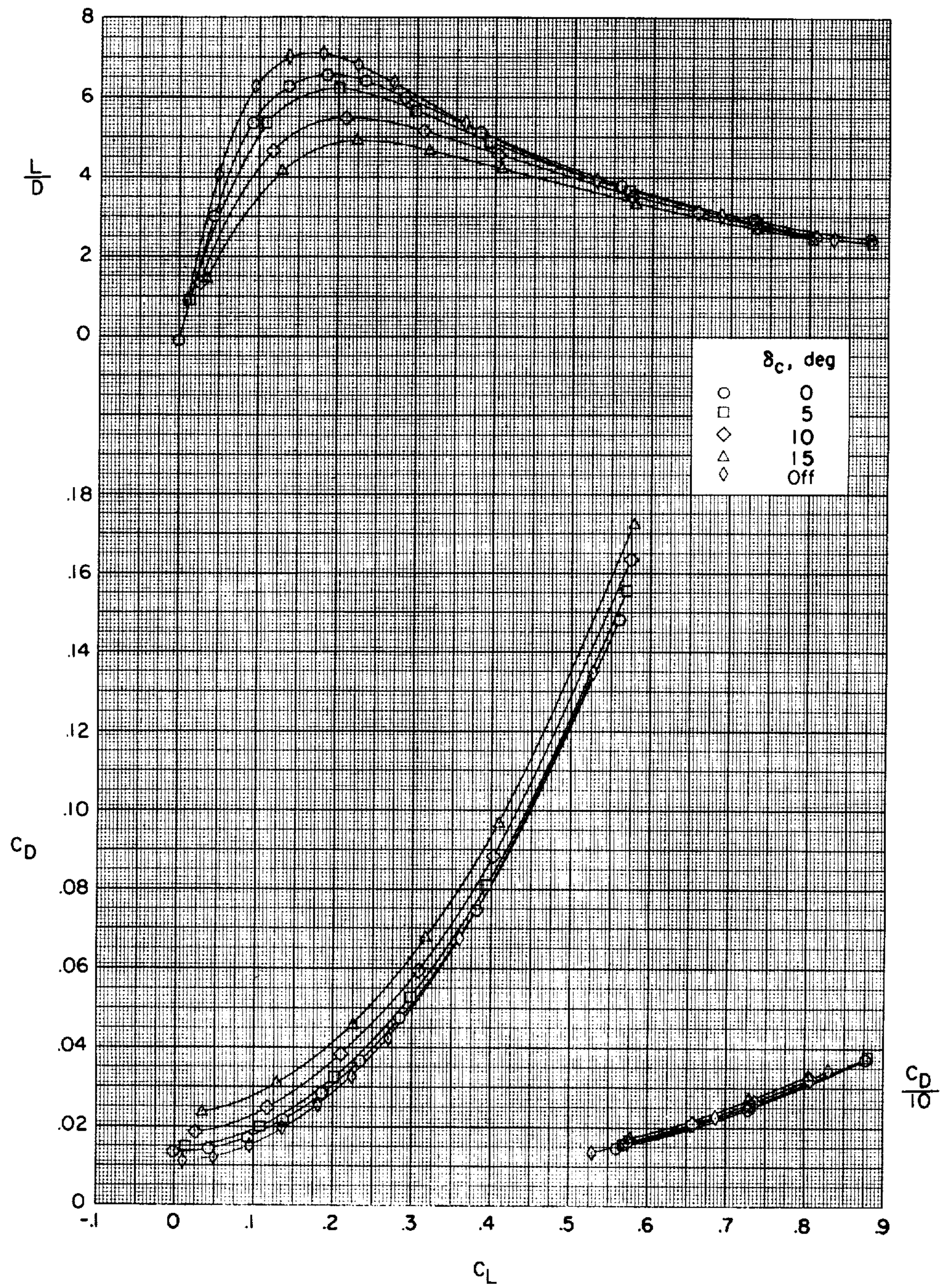


(c) Short body.

Figure 3.- Continued.



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(c) Concluded.

Figure 3.- Concluded.

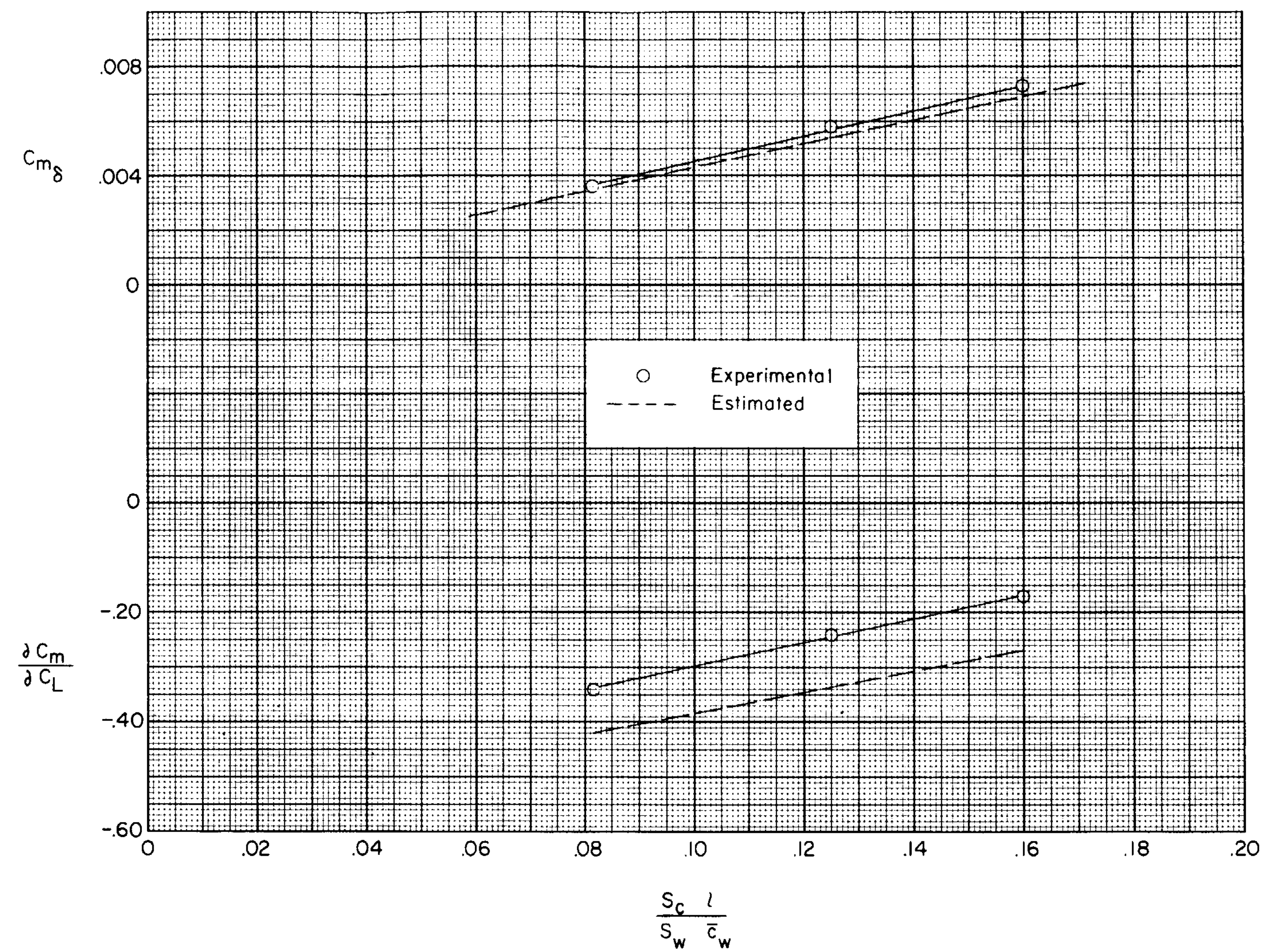

Figure 4.- Variation of canard pitch effectiveness and static longitudinal stability with canard volume coefficient.

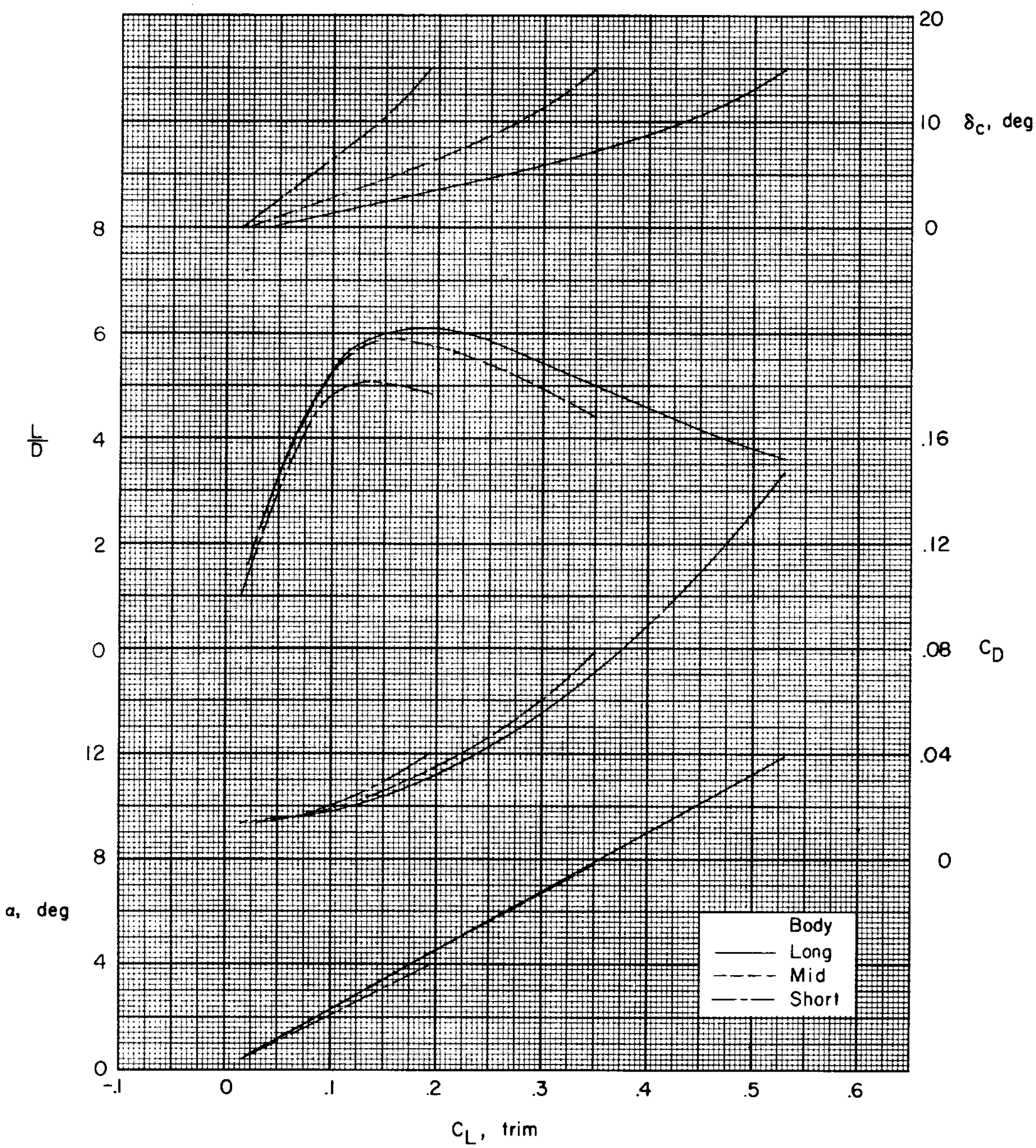

Figure 5.- Effect of body length on longitudinal trim characteristics for a constant center-of-gravity position.

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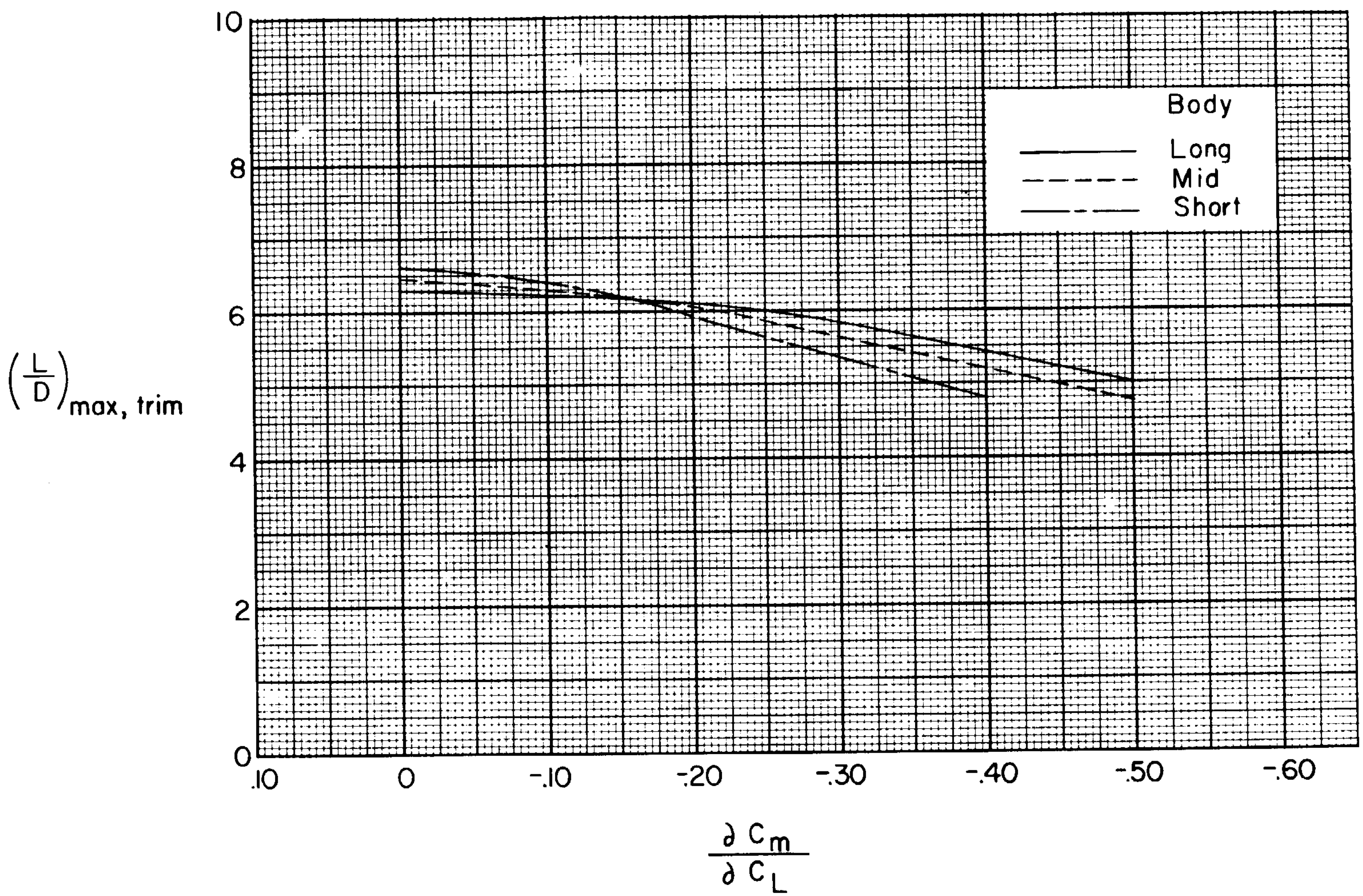

Figure 6.- Variation of maximum trimmed lift-drag ratio with longitudinal stability for various body lengths.

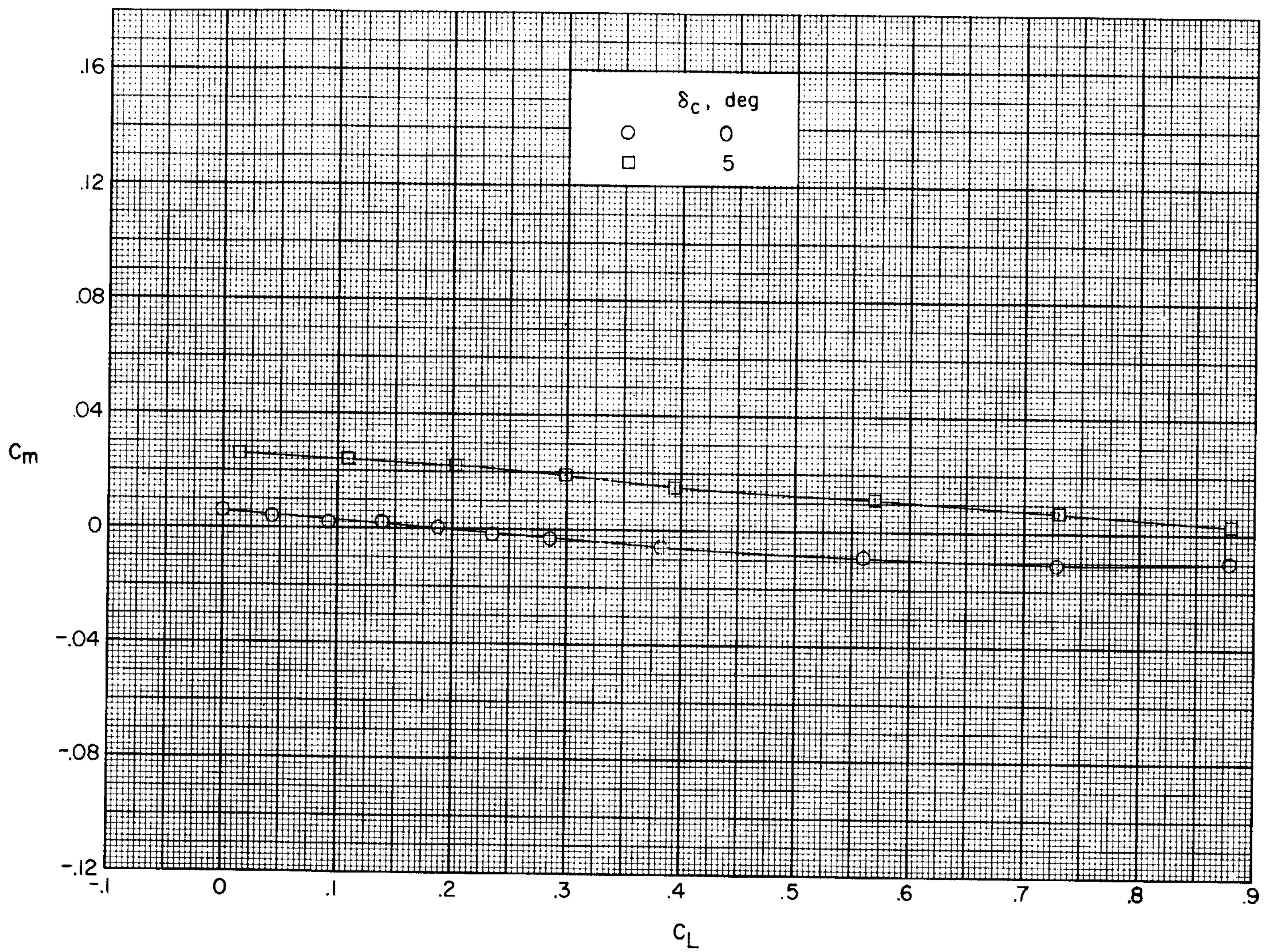

Figure 7.- Pitching-moment characteristics for configuration with the short body for a static margin of $0.03\bar{c}$.

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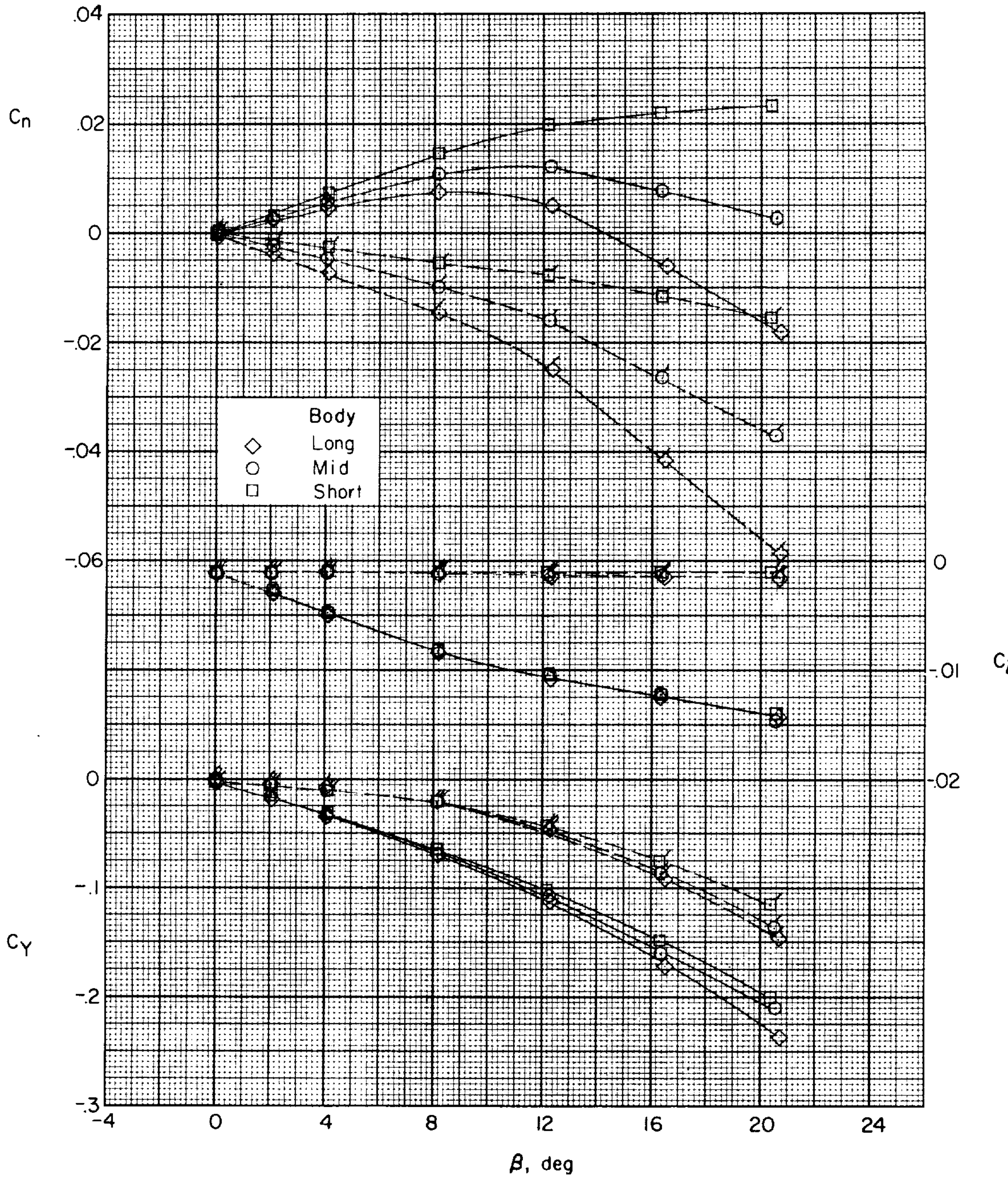
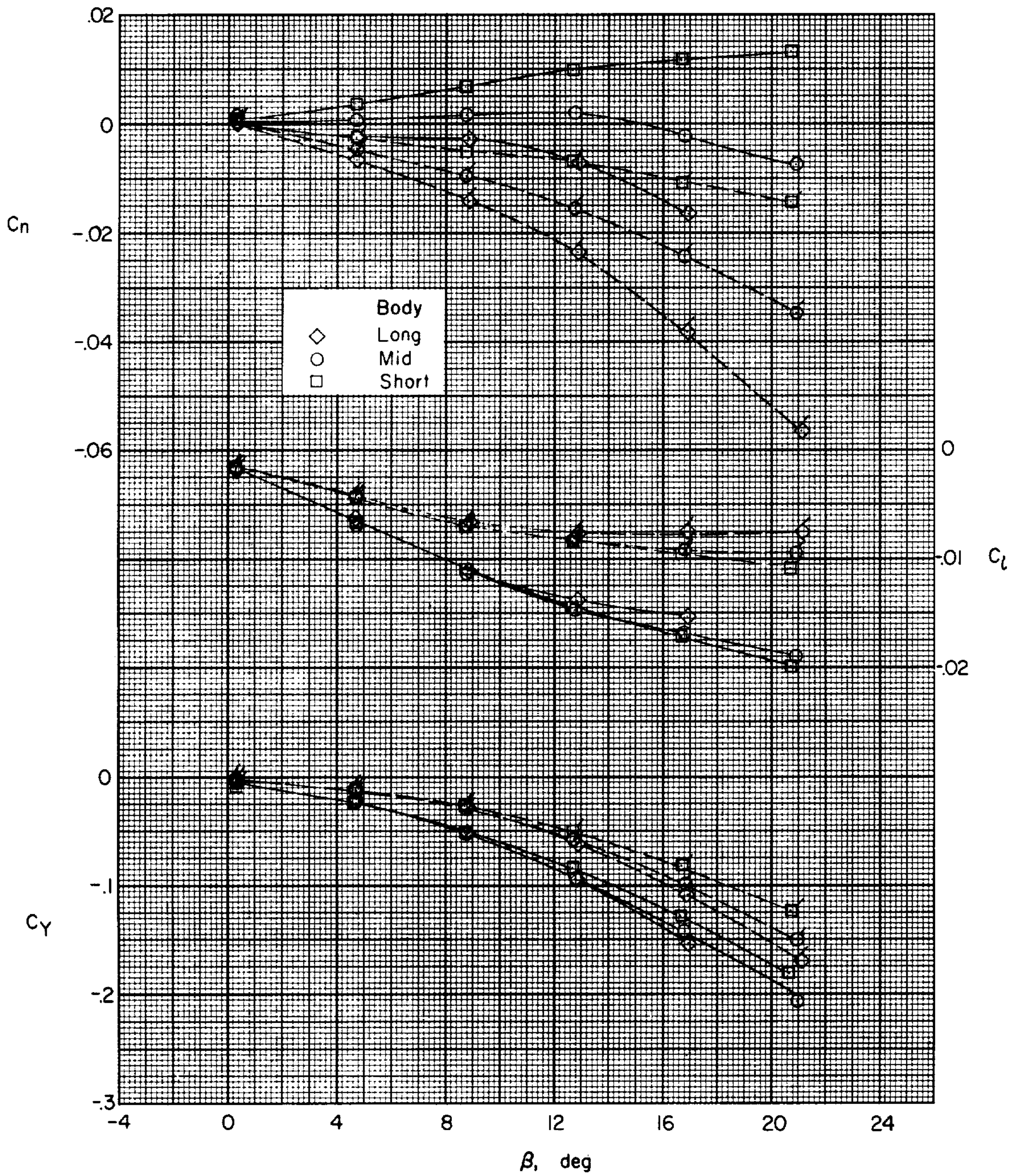


(a) $\alpha \approx 0^{\circ}$.

Figure 8.- Effect of body length on aerodynamic characteristics in sideslip. Flagged symbols indicate vertical tail off. $\delta_c = 0^{\circ}$.



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(b) $\alpha \approx 8.6^{\circ}$.

Figure 8.- Continued.

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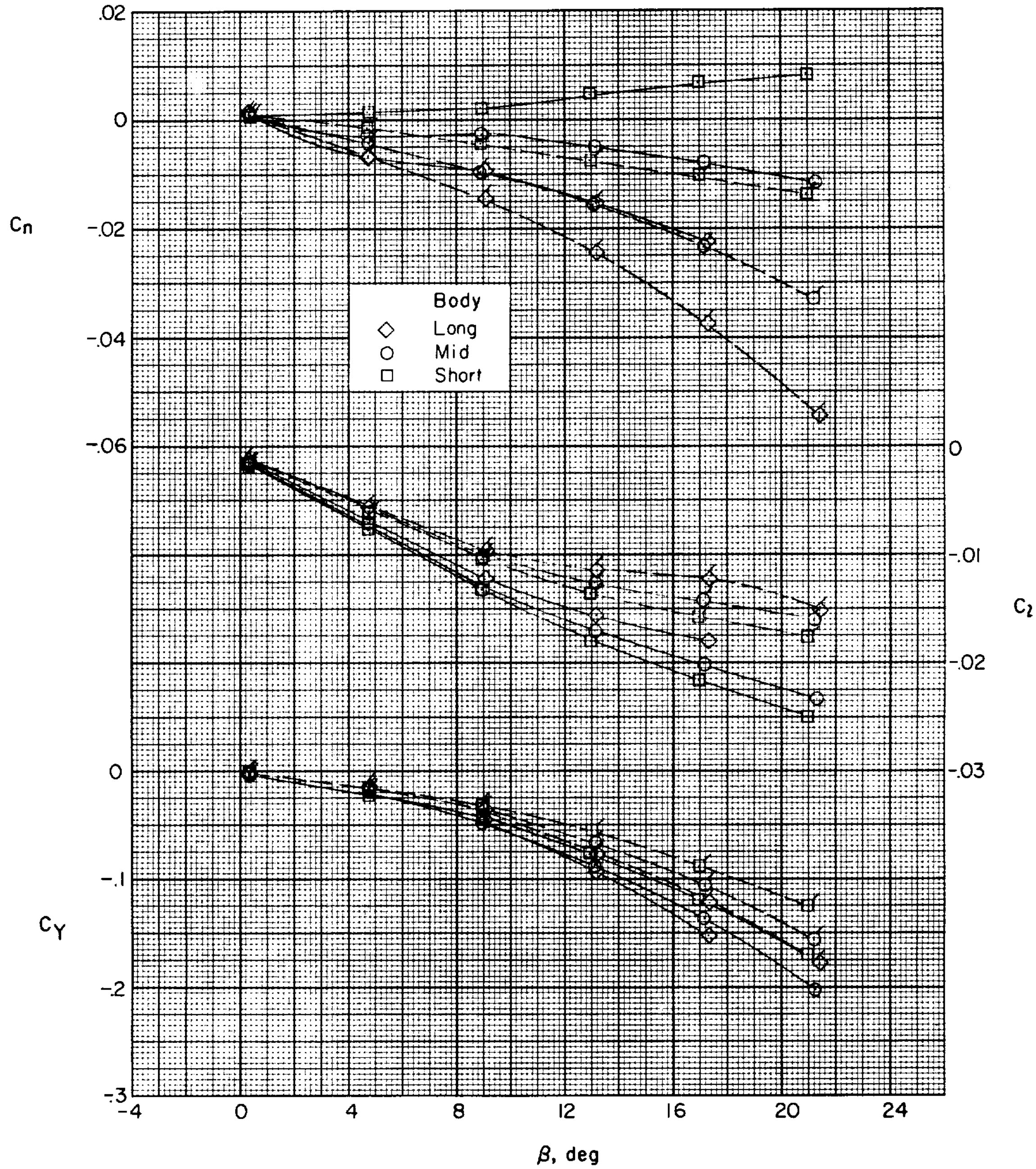
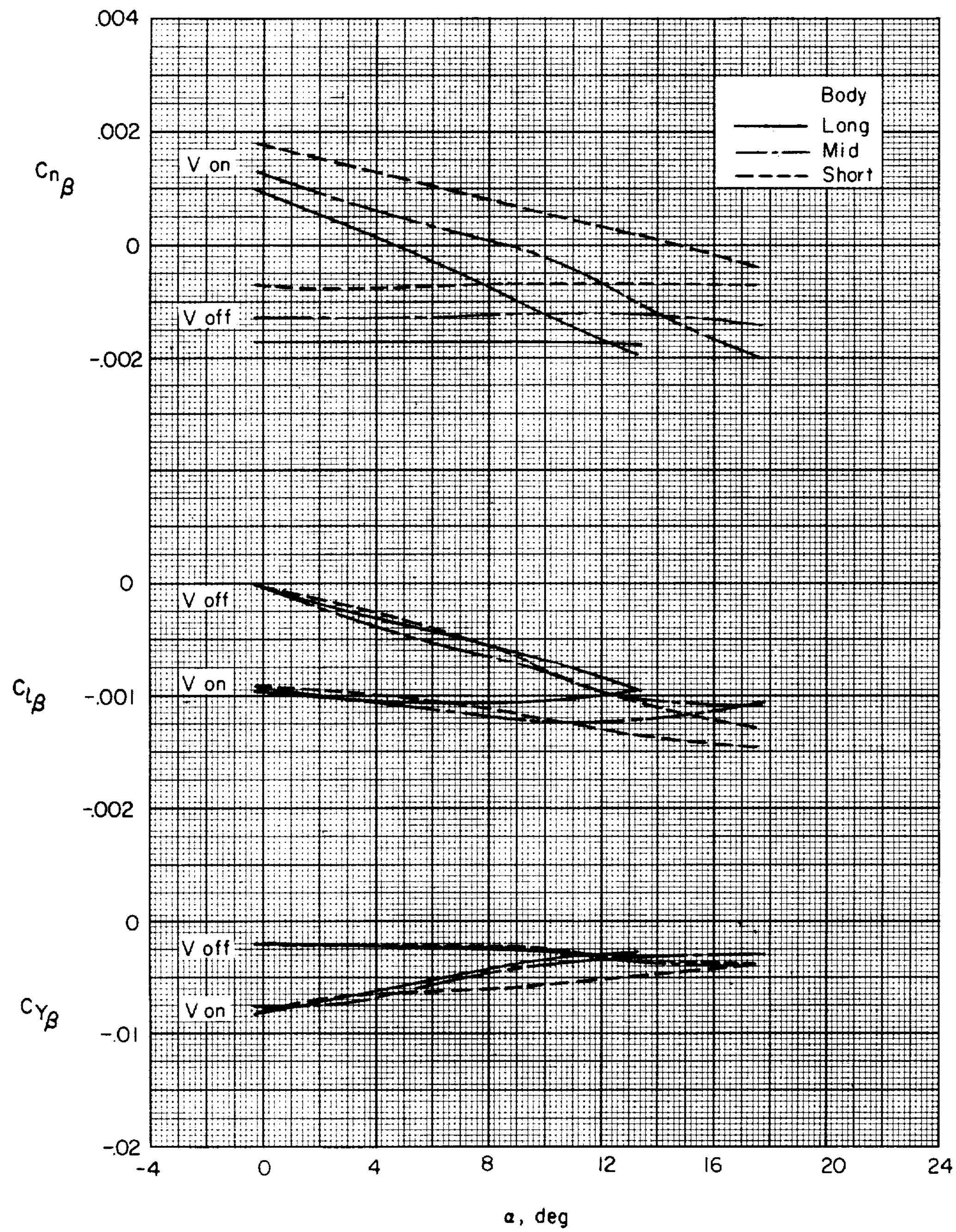


(c) $\alpha \approx 13^o$.

Figure 8.- Concluded.



(a) Canard on.

Figure 9.- Effect of body length on sideslip derivatives for constant center-of-gravity position.

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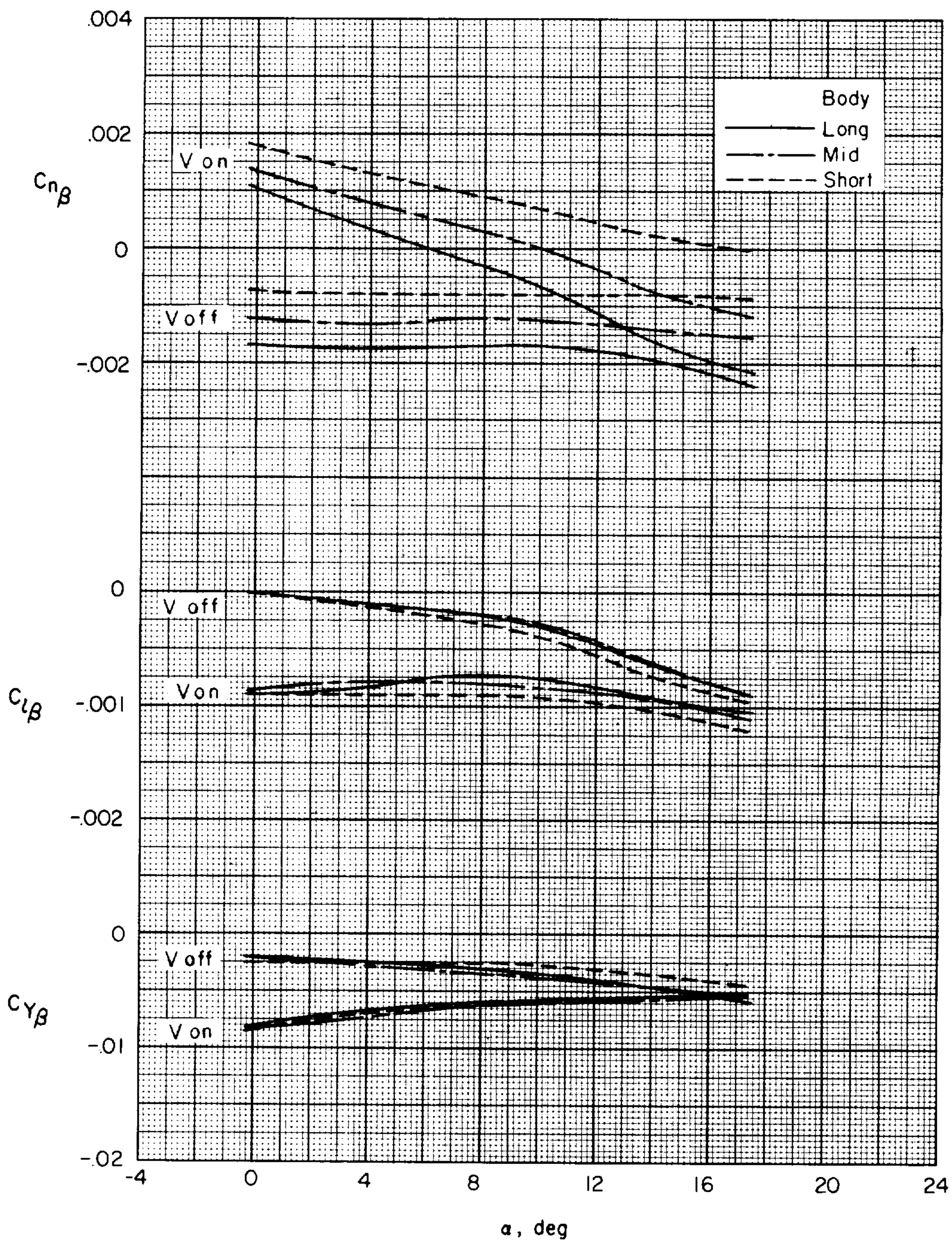

(b) Canard off.

Figure 9.- Concluded.

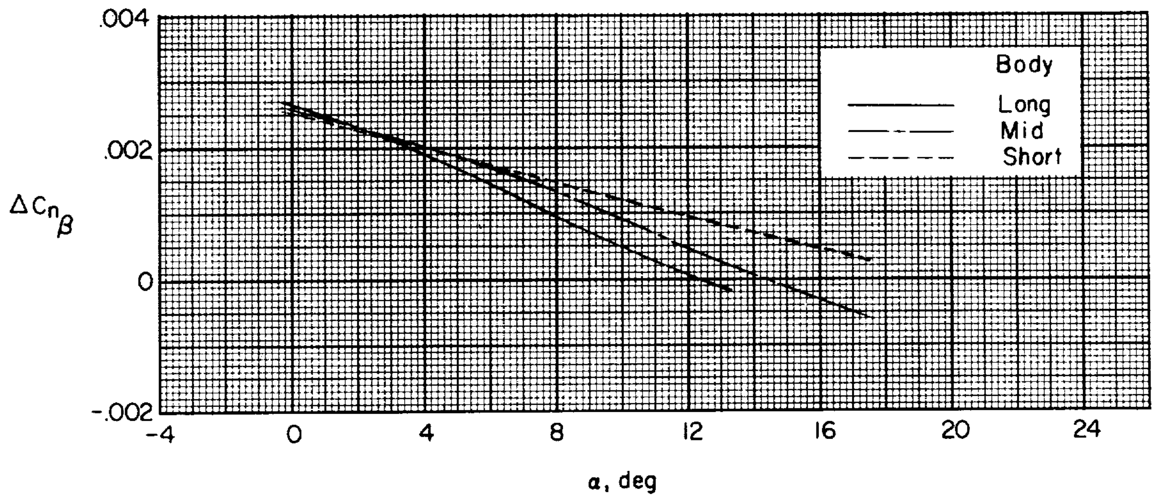

Figure 10.- Effect of body length on tail contribution to directional stability for constant center-of-gravity position. $\delta_c = 0^\circ$.

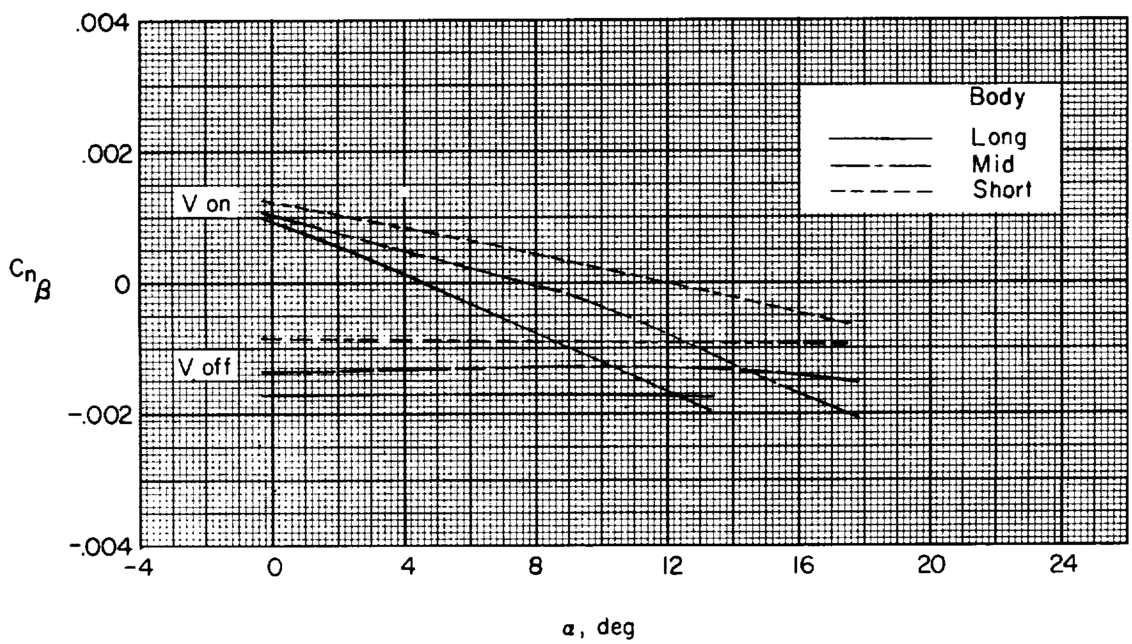

Figure 11.- Effect of body length on directional stability for constant longitudinal stability. $\partial C_m/\partial C_L = -0.17$; $\delta_c = 0^\circ$.

NASA-Langley, 1962

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